ON THE MOTIONS OF SPIRALS

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In a note on Messier 33[1] I made use of Dr. van Maanen's results for the translational motion of the nebula, but not of his results interpreted as internal motions for the same object.[2] Dr. Harlow Shapley has called my attention to this fact and expressed the opinion that van Maanen's measures practically eliminate the island universe theory. It is obvious that the parallax for Messier 33 estimated by van Maanen from the internal motions in this object is not in harmony with the parallax value suggested by me as based upon certain spectroscopic results.[1] I was aware of these facts, and the only reason for not dealing with this discrepancy in the note in question was my desire to discuss in a later paper the present state of the problem of the distances of spirals and in this connection use van Maanen's data. Although agreeing with van Maanen's statement that definite conclusions as to the real meanings of these motions must await further measurements, I will make here some preliminary comments on the exceedingly interesting measures of motions in spirals, recently published by van Maanen.

For two spirals, *N. G. C.* 4594 and *N. G. C.* 224, Pease has found a component of the radial velocity, evidently due to a rotation of the nebulæ in the plane of the spiral arms. The rotation in the first of these objects was discovered by Slipher, and his measurements are confirmed by Pease's investigation. The motion is a purely rotational one, increasing with the distance from the center. The internal motions in four spirals measured by van Maanen from photographic plates separated by intervals of time ranging from 5 to 15 years appear, if interpreted as real motions, to be of another kind, since after subtracting the translational motion the points close to the centers have a rotational velocity practically equal to that of the outlying regions. For Messier 51 and 81 there seems to be a slight increase in the rotational component with distance from center, but in Messier 101 that component decreases a little. As there is no reason to sup-

[1]*Publ. A. S. P.*, **33**, 324, 1921.
[2]*Mount Wilson Contr.*, No. 72, 1921.

pose that we are here dealing with different kinds of spirals, it seems not unlikely that van Maanen's internal motions for spirals are measured too large at the centers.

Preliminary results for the internal motions in Messier 51 were first published by Kostinsky in 1916. He found that the motions in the "outer" spiral arms are apparently outward and clockwise, while in the "inner" arm the turning of the nebula is in the opposite direction. The motions vary within rather large limits and are in the mean 0″.04 — 0″.05 per year.

Other results for the annual motion of this spiral are:

	μ_α	μ_δ	μ_{rot}	μ_{rad}
Lampland	+ 0″.118	— 0″.017	+ 0″.040†	
Schouten	— 0 .028	+ 0 .019	+ 0 .000	— 0 .020
Schouten			— 0 .0073[3]	
Van Maanen . . .	+ 0 .006	+ 0 .001	+ 0 .019	+ 0 .008

Van Maanen's results undoubtedly deserve the highest weight, but Schouten's measures ought not to be entirely ignored. Although he had a somewhat smaller scale, his plates extend over an interval of 24 years. Lampland's values, as pointed out by himself, are of a provisional character.

Van Maanen derived the parallax 0″.0005 for Messier 33 by comparing the difference in radial velocity for the center and for the nebula *N. G. C.* 604, which is assumed to be part of Messier 33, with the angular motion along the spiral arms. An uncertainty is involved in deriving the angle between the plane of the arms and the line of sight. He has not given the value used for this angle, but on the basis of an independent estimate of this quantity the writer derives a parallax of 0″.0004, in substantial agreement with van Maanen's result. From the published values of van Maanen we get in the mean μrot = 0″.020 for a mean distance of 5′ from the center. Values derived from Pease's, Slipher's and Wolf's measures give for three nebulæ at the same distance from the center a mean rotational component of 430 km./sec. Assuming that the size of the linear rotation for both groups of spirals is in the mean the same, we get a mean parallax for the objects in question of 0″.00022.

The proper-motions derived for spirals indicate that the mean parallax is still smaller, as the translational motions, ac-

†Only one nebular point (N. G. C. 5195) is measured.
[3]This value is obtained after excluding two points.

cording to van Maanen, are smaller than the rotational, but the mean radial velocity of translation is of the same order of magnitude as the mean rotational component of the radial velocity. Dr. Curtis found from measuring Crossley plates that the proper-motions do not exceed 3″ per century but the derived values were not considered by him to be real. From a discussion of all micrometric and photographic measures made between 1860-1910, I have found that the motions do not exceed 3″ to 4″ per century. These results must not be misunderstood as meaning that the spirals actually have proper-motions of this size. As will be shown later by a comparison of Curtis's and my results, the poor agreement in the different cases proves that we have obtained only an upper limit for the proper-motions, a limit which will quite certainly be reduced in future researches. The best values we have at present for the proper-motions of spirals are undoubtedly those found by van Maanen for the four objects measured by him, and summarized here.

	μ_α	μ_δ	τ	v
M 33	$-0''.007$	$-0''.002$	$+0''.0063$	$-0''.0009$
M 51	$+0\ .006$	$+0\ .001$	$-0\ .0037$	$+0\ .0017$
M 81	$+0\ .014$	$-0\ .005$	$-0\ .0043$	$-0\ .0055$
M 101	$+0\ .004$	$-0\ .012$	$-0\ .0050$	$-0\ .0111$

The τ and v components of the proper-motions are calculated. assuming the apex of the Sun's motion relative to the spirals to be R. A. $= 23^h.0$, Dec. $= +77°$, derived from my recent solution, using the radial velocities for 38 spirals. The proper-motions combined with the radial velocities give, according to known methods, the following mean parallaxes for the four objects:

π	MATERIAL
$0''.000064$	τ components
$0\ .000064$	v "
$0\ .000040$	v "

In the solution for the solar apex Campbell's K term is introduced. The only difference of importance between the new solution and the earlier ones, in which a smaller amount of material was used, is that this term has increased from 660 km./sec. to 810 km./sec. The introduction of the K term is well justified, but even if we drop it, the order of magnitude for

the mean parallaxes derived from the motions of the spirals will not be sensibly changed.

There is another point of view from which we get an estimate of the parallaxes for spirals. The size of the radial velocity seems to depend upon the galactic latitude, in the sense that the velocity increases with decreasing angular distances from the galactic poles.[4] The correlation is not very definite, but it is noteworthy that velocities of 800 km. and larger are to be found close to the poles of the Galaxy. At the same time most of the velocities are positive. Thus it seems that one possible interpretation of the measures is that the spirals have a systematic motion away from us, that is to say, a motion at right angles to the plane of the Galaxy. This assumption supplies an independent, although somewhat hypothetical, avenue of approach to a knowledge of the distances of these objects. If K is the space motion of the spirals in the direction of the Milky Way poles, μ the annual proper motion, and β the galactic latitude, it follows that

$$\pi = 4.74 \frac{\mu \sec. \beta}{K}$$

where π is the parallax.

Assuming $K = 810$ km./sec., we get the expression $\pi = 0''.0058\, \mu \sec. \beta$. This gives for the four spirals:

	π
M 33	0″.000037
M 51	0 .000076
M 81	0 .000054
M 101	0 .000137

As Messier 33 seems to extend over an area[5] of at least 8°x 8° it follows that its diameter is about 13,000 light-years.

Using the τ and υ components of van Maanen's proper-motions we get a mean parallax of 0″.000056 for the four spirals, and, assuming a systematic motion at right angles to the galactic plane, 0″.000077. Giving the later result half weight, as it is the more hypothetical, we obtain the mean parallax 0″.000063. Thus it is evident that the translational motion measured by van Maanen suggests distances for the spirals 6 to 10 times larger than the distances derived by using the internal motions. Parallaxes obtained by assigning to the brightest

[4]First pointed out by Shapley, in *Mount Wilson Contr.*, No. 161, 1919.

resolved stars in spirals an absolute magnitude equal to that of the brightest stars of our stellar system give still larger distances. This is also true of distances obtained by comparing the galactic novæ with novæ recorded in spirals. To sum up: different methods give for spiral nebulæ distances ranging from about 10,000 light-years to 1,500,000 light-years. The truth may lie between these two extremes, or the motions may have been found with such an accuracy that they give the right order of magnitude for the parallaxes. From the work of recent years it is now evident that for the spirals only distances of the order of tens of thousands of light-years or more will have to be considered in future determinations. The spirals are evidently situated at distances at least comparable with those of globular clusters. We have very likely to deal with millions of spirals, and it would be strange if we should have the largest of the spirals in our neighborhood. It is more natural to assume the spirals to have roughly the same linear dimensions, and that the smaller angular diameters in the mean indicate the more distant objects. Thus the visible universe in the direction of the poles of the Milky Way has an extension conservatively estimated at 2,000,000 light-years.

Even if we have to reject the so-called "island universe" theory, in the sense that spirals are in size comparable with the Galaxy, it still seems necessary to regard the spirals as mainly composed of stars.[6]

The question of the dimensions of our stellar system is not yet answered definitely. Many astronomers may be willing to accept the value of 300,000 light-years suggested by Shapley from his studies of the distribution of globular clusters, but most of the evidence from stellar statistics is in harmony with a smaller extent of the Milky Way system. From Shapley's own work it seems improbable that the Milky Way has the suggested extension. As is well known, he finds that the center of the system of globulars is situated 68,000 light-years away from us. The most distant cluster in that direction has a distance of 220,000 light-years. Thus the distance from the center to this cluster is 150,000 light-years. Assuming the center of the Milky

[5] *Publ. A. S. P.*, **33**, 1921.
[6] *Publ. A. S. P.*, **33**, 324, 1921.

Way system to coincide with the center of the globular clusters, and further assuming the two systems to be concentric, he finds that the diameter of our stellar system is 300,000 light-years. Now, globular clusters are lacking in the direction opposite to that of the center of the system (*Auriga, Gemini, Orion*). The farthest *open* cluster in that part of our stellar system, N. G. C. 2266, has, according to Shapley, a distance of 33,000 light-years as projected upon the galactic plane. This object seems to be exceptionally situated, as all other open clusters in that direction are considerably nearer. Moreover, many lines of evidence suggest that the star clouds composing the Milky Way in this region are not more distant than 12,000 light-years. Accepting the boundary of our stellar system in the said direction as 33,000 light-years distant, we find, without changing Shapley's scale, that the radius of the stellar system measured from this limit to the center in *Sagittarius* is 100,000 light-years. Even so, the galactic system will be considerably larger than generally assumed before. A more detailed discussion is reserved for a later time.

Van Maanen's measures enable us to draw, on the basis of certain assumptions, some interesting conclusions concerning the masses of the four spirals. We use the mean of the parallax values calculated, first, by assuming a stream motion in the direction of the Milky Way Poles, and secondly, by assuming the v components of the motions to be principally a reflex of the Sun's motion. From the formula for a circular orbit, $M + m = \frac{v\,r^2}{k}$ where M and m are respectively the masses of the central nucleus and a particle at a distance r astronomical units from the center, v the linear velocity in astronomical units per day, and k the universal constant, we get the following expression for the central mass: $M = [3.71856]\ \mu^2\text{rot.}\ \tan d\ \eta^{-3}$, where d is the distance from the center in minutes of arc for a certain particle, and π the parallax. The resulting values are shown in the following table:

	ADOPTED π	μrot	DIST. FROM CENTER	MASS (SUN = 1)
M 33	0".00003	0".017	8'	130×10^9
M 51	0 .00005	19	3	13×10^9
M 81	0 .00007	29	4	15×10^9
M 101	0 .00012	0 .021	5	2×10^9

Using van Maanen's parallax for M33 we get 28×10^6 for the central mass. The values are astonishingly high and should indicate an enormous density for the central nuclei which, in two cases, M 33 and M 101, seem not to have any exceptional extension in space, nor to exceed very much in brightness the other parts of the nebula.

Even if future determinations considerably diminish the size of the internal motions, the conclusion that the spirals are massive bodies will hold, as the distances seem to exceed 10,000 light-years. This result excludes the theories dealing with spirals as the origin of solar systems, but it gives some support to views expressed in Jeans' theory, and also to the island universe hypothesis. For the purpose of comparison, it may be mentioned that the mass of our own stellar system can be estimated at 3×10^6 that of the Sun. This includes only the stars, and as we do not know the proportion between luminous and dark matter in our stellar universe, this figure is only a lower limit.

It should be noted that the most outlying points in the spirals measured by van Maanen have performed only a couple of revolutions around the nucleus. The matter we see in the measured spirals, if moving with a rather constant velocity, as indicated by the measures, must have been ejected during an interval of time of about 100,000 to 300,000 years.[7] There is no reason to suppose that all the spirals have started their development at the same time, and moreover it is very likely that we observe spirals separated in time by hundreds of thousands and millions of years. Thus the different spirals are not observed in the same stage of development, a conclusion also supported from the great variety in the spiral structure. As the measured spirals are younger than 300,000 years, we reach the absurd conclusion that the stars generated in spirals are restricted to a life, as luminous bodies, shorter than this interval of time. As shown by Shapley, 100,000 years is a very short period in the life of a star.

Another strange conclusion is that if the spirals are, according to Jeans, star-producing mechanisms, the stars must be generated very rapidly. In the spiral Messier 33 about 30,000 star-

[7]This conclusion was also reached by Jeans, *Observatory*, **34**, 353, 1921.

like objects composing the spiral arms are seen on modern photographs. If these are stars produced at the center of the spiral, then according to what was said above they are not older than 300,000 years, and in those stars we are observing the "youngsters" of the stellar family. As there is considerable difference in color between the center of the spirals and the arms (Seares's phenomenon) it is unlikely that the luminous matter in the spirals has existed so short a time as suggested from the measures of the internal motions.

In the *Bull. of the Astr. Institutes* of the Netherlandes, Nov. 8, 1922, Kapteyn and van Rhijn give new proper-motions for 14 Cepheids of the cluster variable type. The derived mean parallax is 7.6 times that found by Shapley, suggesting that his scale for the universe is 7.6 times too large. An uncertainty is involved in deriving the mean parallax by assuming the Sun's linear motion to be 19.5 km./sec., but our present knowledge of the motion of Cepheids does not conflict with this assumption. The authors point out that distances derived by Schouten for three globular clusters using the luminosity law, also are 7.6 times smaller than Shapley's. Much weight should not be attached to this fact, as practically the same method used by me has given distances 1.4 smaller than Shapley's. Still several facts indicate the necessity of diminishing Shapley's cluster distances. In the *Ap. J.* **54**, 85, 1922, Lindblad publishes spectra for some bright stars in the galactic cluster M. 11. From his data a parallax of $0''.00040$ results, corresponding to a distance one-third of that of Shapley's. The apparent distribution of long period variables shows that these concentrate in the *Sagittarius* region. Proper-motions and radial velocities suggest a value of -2.8 for the absolute magnitude at maximum. Thus we get the distance to the center of 10,000 light-years, while Shapley finds 68,000. Of course it is possible that these objects, although connected with the central region, actually do not reach the center. From other evidence it seems likely that Shapley's scale for the universe ought to be reduced by 3 or 4 times, which gives the Milky Way System an extension in its plane of 50,000-65,000 light-years.